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A GENERALIZED HIERARCHIAL GOAL DECOMPOSITION MODEL OF RESOURCE ALLOCATION WITHIN A UNIVERSITY

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Summary

The purpose of this study is to develop a systematic and rational approach to the university resource allocation problem based upon the use of the Davis generalized hierarchical goal decomposition model. This university model represents the first successful goal programming-decomposition modelling effort of an actual administration situation. The model was solved on a CDC CYBER-175 computer. Although the formulation was enormous, convergence was rapid. The results of this research clearly confirm that organizational models based upon mathematical programming techniques can offer a systematic and viable approach to organizational design, multi-period planning, and resource allocation in decentralized organizations.

Acknowledgment

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Key Words

ORGANIZATIONAL STUDIES (DECOMPOSITION, DECISION PROCESSES, RESOURCE ALLOCATION), UNIVERSITY PLANNING, RESOURCE ALLOCATION, BUDGETING SYSTEMS, and MATHEMATICAL MODELS-GOAL PROGRAMMING

A Generalized Hierarchical Goal Decomposition Model of Resource Allocation within a University

I. Introduction

During the coming decade, most institutions of higher education will enter a no-growth or perhaps negative-growth era. The likely continuance of historically high inflation will place additional burdens upon these institutions. In this kind of demographic and economic environment, the *status quo* will be difficult if not impossible to maintain; university programs will have to be consolidated, reduced, and/or abandoned in order to accommodate operational and financial constraints. In this setting, universities must boldly come to grips with the problems of resource allocation. The purpose of this study is to develop a systematic and rational approach to the university resource allocation problem.

As Richard Cyert [5, p. 7] has remarked, even though nonprofit (*viz*, educational, medical, and government) institutions play a major role in sustaining national welfare, "there has been little attention to these areas by business management scholars. [These scholars] have tended to emphasize the [for-profit] business firm without looking for a transfer of knowledge" to the nonprofit sector.

This study attempts to fill the void noted by Cyert. It describes the implementation of a university resource allocation-planning model that utilizes the generalized hierarchical goal decomposition model (GHM) recently developed by Wayne J. Davis [7]. Unlike the strict maximization or minimization linear programming decomposition models (see [1, 6, 15, 19, and 27]), the GHM is an extension of the goal programming/

decomposition organizational models developed by Ruefli [25, 26], Freeland and Baker [14], and Davis and Talavage [10].

Unfortunately, although the first of these organizational models was introduced over ten years, no prior modelling effort has successfully implemented and solved an actual administrative solution in a decomposition-goal programming format. This study describes the first successful implementation of such a model. The successful results of this research clearly confirm that organizational models based upon mathematical programming techniques can offer a systematic and viable approach to organizational design and multi-period planning and resource allocation in a real world decentralized organization.

In addition to this introduction, this paper contains five sections. Section II provides a brief overview of resource allocation problems within a decentralized university setting. A complete discussion of the Davis generalized hierarchical model is given in Section III. In addition to the specification of the GHM's three levels, the model's solution procedures and properties are discussed. The fourth section provides the specification of the three levels of university resource allocation model and a brief description of organizational priority weightings. Section V describes the model's computation requirements and solutions characteristics. Also the results of model revision and sensitivity analysis are reported. The final section contain a summary of the paper and discusses the need for continued research.

II. Resource Allocation in a Decentralized University Setting

A university resembles a divisionalized corporation; however, instead of separate divisions, representing operating subunits or profit centers, a typical university is composed of departments, schools, and colleges. It is well established that optimal transfer prices within a for-profit divisionalized corporation must consider _all_ corporate constraints and opportunity costs [12]. _A priori_ one can argue that the allocation of resources within a university must also consider all organizational constraints, economies of scale, and opportunity costs. However because a university cannot point to a unique goal such as shareholder wealth or economic profit maximization, the measurement of these opportunity costs is difficult. Based upon institutional priorities, a university typically pursues a set of organizational objectives which are targeted at achieving teaching, research, and public service goals. Indeed the literature is replete with examples proposing the use of multicriteria or goal programming in university resource allocation. For a representative sample see [13, 16, 17, 18, 20, 22, 23, 29, and 30].

Unfortunately a careful perusal of these studies reveals that each focuses upon a component of the university organization. That is these studies concentrate upon an individual department, a college, or university administrative problem. None highlights the problems created by divergencies in goals and priorities as one moves through the various levels of the organization's hierarchy.

Given the current demographic and economic environment in higher education it is essential that resources be allocated in accordance with organizational goals and priorities. Further the allocation process must consider the simultaneous interactions, constraints, and complexities of funding and staffing decisions for department, college, and university programs. The following section describes an organizational model or algorithm that appears to offer great promise in dealing with resource allocation, budgeting, and other managerial issues faced by decentralized organizations.

III. The Generalized Hierarchical Model

Like its predecessors, the GHM follows an iterative solution procedure and is designed to capture the structure of a three level hierarchical organization similar to that depicted in Figure 1. It should be noted that the GHM can easily accommodate an n level decentralized organization; however, for ease of exposition, only three are presented. As seen in Figure 1, there is one central or supremal unit, whose principal organizational responsibility and role are setting goals and allocating resources. Subordinate to the central unit are M management units. These organizations coordinate their subordinate operating units and allocate local resources, such that the programs and policies under the authority and responsibility of each management unit conform to overall organizational goals and priorities. Each operating unit (sometimes called an "infimal subsystem" in the literature) is designated by a single index, i. Given M managers, it is possible to define a series of integers $r_0, r_1, \ldots, r_M$, such that operating units $(r_{k-1} + 1)$ through r_k report to manager k. Assuming a total of N operating units, r_0 equals 0, and r_M equals N. The responsibility and role of each operating unit are to carry out the organizational operations of the firm and generate proposal revisions representing alternative levels of organizational output.

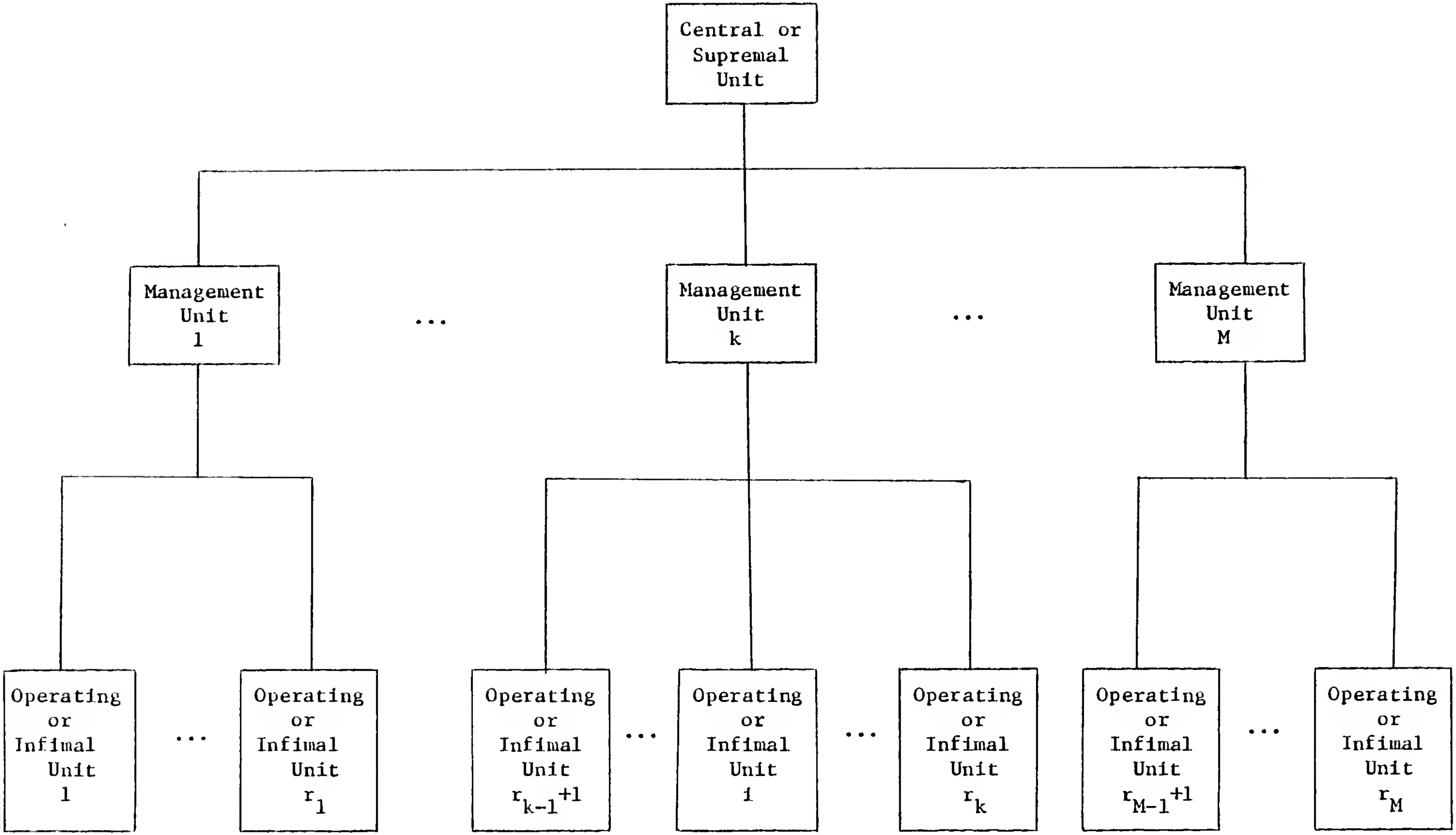

Figure 1

The Hierarchical Organization of the GHM

Mathematical Structure of the GHM

The mathematical structure of the algorithm is defined by equations (1-14.i) given in Table 1. Equations (1-4) pertain to the central units problems, (5.k-10.i) to the management units, and (11-14) to the operating units. The levels will be discussed separately, beginning with the management unit and followed by the central or operating problems.

A. The management unit subproblem.

Each management unit (k=1,...,M) has two sets of goals. The first is a m_k vector, G_k^τ, which defines a set of external goals imposed by the central unit at iteration τ. The second set is represented by a m_k' vector of internal goals, g_k. These internal goals are not modified during the algorithm's solution procedure, and they can provide a certain amount of autonomy for each management unit. There are two m_k vectors, $Y_k^{+,\tau}$ and $Y_k^{-,\tau}$, which are respectively positive and negative deviation vectors at iteration τ from the external goal vector G_k^τ. In addition there are two m_k' vectors, $y_k^{+,\tau}$ and $y_k^{+,\tau}$, which represent positive and negative deviations from the internal goal vector, g_k.

The kth management unit can select from a set of n_i vectors, $X_i^1,\ldots,X_i^t$. These vectors contain a set of proposals or operating decisions generated during iterations 1 through t by operating unit i, $i = r_{k-1} + 1,\ldots,r_k$. B_i and B_i' $(i=r_{k-1} + 1,\ldots,r_k)$ are $(n_i \times m_k)$ and $(n_i \times m_k')$ matrices respectively. These linearly relate the ith operating unit's decision to the kth management unit's external and internal goals. Associated with each X_i^τ vector is a n_i vector, C_i. The multiplication, $C_i X_i^\tau$, yields the cost of a particular proposal vector or

Table 1

The Mathematical Structure of the GHM

The Central Unit Problem: Equation #

Minimize: $$\sum_{k=1}^{M} \{C_{G_k} G_k^{t+1} + W_k^+ S_k^{+,t+1} + W_k^- S_k^{-,t+1}\} = Z^{t+1} \quad (1)$$

Subject to:

$$I_{m_k} G_k^{t+1} + I_{m_k}^+ S_k^{+,t+1} - I_{m_k} S_k^{-,t+1} = G_k^t + Y_k^{+,t} - Y_k^{-,t} \quad (2)$$

(for k = 1,...,M),

where I_{m_k} is a $(m_k \times m_k)$ identity matrix.

$$\sum_{k=1}^{M} P_k G_k^{t+1} \lesseqgtr G_0 \quad (3)$$

$$G_k^{t+1},\ S_k^{+,t+1},\ \text{and } S_k^{-,t+1} \geq 0 \quad (4)$$

The kth Management Unit Problem: (k = 1,...,M)

Minimize: $$\sum_{i=(r_{k-1}+1)}^{r_k} \sum_{\tau=1}^{t} C_i X_i^\tau \lambda_i^\tau + W_k^+ Y_k^{-,t} + W_k^- Y_k^{-,t} + w_k^+ y_k^{+,t} + w_k^- y_k^{-,t} \quad (5.k)$$

Subject to:

$$\sum_{i=(r_{k-1}+1)}^{r_k} \sum_{\tau=1}^{t} B_i X_i^\tau \lambda_i^\tau - I_{m_k} Y_k^{+,t} + I_{m_k} Y_k^{-,t} = G_k^t \quad (6.k)$$

$$\sum_{i=(r_{k-1}+1)}^{r_k} \sum_{\tau=1}^{t} B_i' X_i^\tau \lambda_i^\tau - I_{m_k'} y_k^{+,t} + I_{m_k'} y_k^{-,t} = g_k \quad (7.k)$$

$$\sum_{\tau=1}^{t} \lambda_i^\tau = 1 \quad (\text{for } i = r_{k-1}+1,\dots,r_k) \quad (8.i)$$

$$\lambda_i^\tau,\ Y_k^{+,t},\ Y_k^{-,t},\ y_k^{+,t},\ \text{and } y_k^{-,t} \geq 0 \quad (9.k)$$

Equation #

$$\gamma_i^{t+1} = \Gamma_i[X_i^{*,t},\ G_k^t,\ Y_k^{+,t},\ Y_k^{-,t},\ y_k^{+,t},\ y_k^{-,t}]$$

$$\text{(for } i = r_{k-1}+1,\ldots,r_k\text{), where } X_i^{*,t} = \sum_{\tau=1}^{t} X_i^{\tau}\lambda_i^{\tau} \qquad (10.i)$$

The ith Operating Unit Problem: $(i = 1,\ldots,N)$

Minimize: $$C_i X_i^{t+1} + \Omega_i^{+}\phi_i^{+,t+1} + \Omega_i^{-}\phi_i^{-,t+1} \qquad (11.i)$$

Subject to:

$$B_i X_i^{t+1} - I_{n_i}\phi_i^{+,t+1} + I_{n_i}\phi_i^{-,t+1} = \gamma_i^{t+1} \qquad (12.i)$$

$$D_i X_i^{t+1} \lesseqgtr F_i \qquad (13.i)$$

$$X_i^{t+1},\ \phi_i^{+,t+1},\ \text{and}\ \phi_i^{-,t+1} \geq 0 \qquad (14.i)$$

operating program. Also in equation (5.k) one observes W_k^+ and W_k^- as well as w_k^+ and w_k^-. These m_k and m_k' vectors are penalty weights associated with the $Y_k^{+,\tau}$, $Y_k^{-,\tau}$, $y_k^{+,\tau}$, and $y_k^{-,\tau}$ deviation variables. Parenthetically, it should be noted the omission of the c_i vectors reduces the kth management unit problem formulation to a standard goal programming format. The same is true for central and operating unit problems if the cost vectors, C_{G_k} (k=1,...,M) and C_i (i=1,...,N), are assumed to be null in equations (1) and (11.i). All cost vectors were assumed to be null in the university planning model described in the subsequent section. However, as will be seen shortly, operating costs and budget limitations were incorporated in the X_i^τ and G_k^τ vectors. For other applications, inclusion of these cost vectors directly into objective functions may be warranted; see for example the design problem given in [9].

In solving its problem, each management unit selects a composite n_i vector of operating programs, $X_i^{*,t}$, that have been submitted over the previous t iterations. This is accomplished by selecting values for λ_i^τ (τ=1,...,t and $i=r_{k-1}+1,\ldots,r_k$) that achieve the priorities established in equation (5.k). This convex combination requirement given in equation (8.i) allows each management unit to have a mathematical "memory" of its operating units' previous proposals, and is in the spirit of convex combination requirement included in the original Dantzig and Wolfe original decomposition formulation [6]. Once an optimal solution (in the goal programming sense) is found, the kth management unit passes its information up and down the organization's hierarchy. The central unit is "told" how close the management unit came to achieving the goals it was given for iteration t, G_k^t, and the subordinate operating units are given a n_i vector of goals, γ_i^{t+1}, $(i=r_{k-1}+1,\ldots,r_k)$. The γ_i^{t+1} vectors provide direction to each operating unit in formulating new proposals which can potentially improve goal achievement at iteration t+1. A discussion of the functional form of γ_i^{t+1} is given in the section immediately following the description of the operating unit's problems.

B. <u>The central unit subproblem.</u>

As seen in equations (1-4) the central unit's principal task is the selection of new goal vectors G_k^{t+1} $(k=1,\ldots,M)$ for its management units. The central unit optimizes its objective function value, Z^{t+1}, in a traditional goal programming sense (at least for purposes of this study). This is done by minimizing $S_k^{+,t+1}$ and $S_k^{-,t+1}$ (for $k=1,\ldots,M$); these are m_k vectors of positive and negative deviations from the over-achieved and under-achieved goal values generated at iteration t. In determining the new goal vectors the central unit must satisfy the constraints given in equation (3). Here G_0 is a m_0 vector of overall organizational goals and P_k $(k=1,\ldots,M)$ is a matrix that linearly relates the goal vector, G_k^{t+1}, to the global university goals in G_0.

C. <u>The operating unit subproblem.</u>

The operating units $(i=1,\ldots,N)$ have a structure that is almost identical to the central unit. The n_i-length vector, Ω_i^+ and Ω_i^-, are traditional goal programming priority weights assigned to ϕ_i^+ and ϕ_i^-, n_i-length positive and negative deviation vectors from the goal vector γ_i^t. X_i^{t+1} is an n_i vector containing the unit's operating decisions.

F_i is a ℓ_i-vector of inflexible operating constraints, and D_i is a (ℓ_i x n_i) matrix of linear relationships that relates the unit's operating decisions to F_i.

Solution Procedure of the GHM

The GHM algorithm follows an iterative information and goal revision process in achieving a final solution. Figure 2 outlines this process. Initially the central unit selects preliminary goal values for its managers. These goals are of course subject to the constraints given in equation (3). Simultaneously each operating unit provides its superior with an initial set of operating decisions that fall within the feasible region described in equation (13.i). On the first iteration, the elements of the operating units' goal vectors, Y_i^1 (i=1,...,N), are initialized to zero. Thus the units' proposals satisfy only the minimum specifications given in (13.i). Accordingly, this level of the algorithm resembles a "zero-base" [24] budgeting system.

Utilizing this information each management unit formulates and solves its problem generating values for $Y_k^{+,t}$, $Y_k^{-,t}$, $y_k^{+,t}$, and $y_k^{-,t}$ (k=1,...,M). At this juncture two alternatives are available: (1) ask the central unit for a new set of revised goals, G_k^{t+1} and (2) ask the operating units to revise their proposals so that they conform more closely with the current external goals, G_k^t, and internal goals, g_k. Alternative (2) will be discussed initially.

Equations (10.i) and (12.i) provide insight into this goal revision process. At iteration t assume that management unit k believes that its external goal vector will be held constant. Further assume it believes

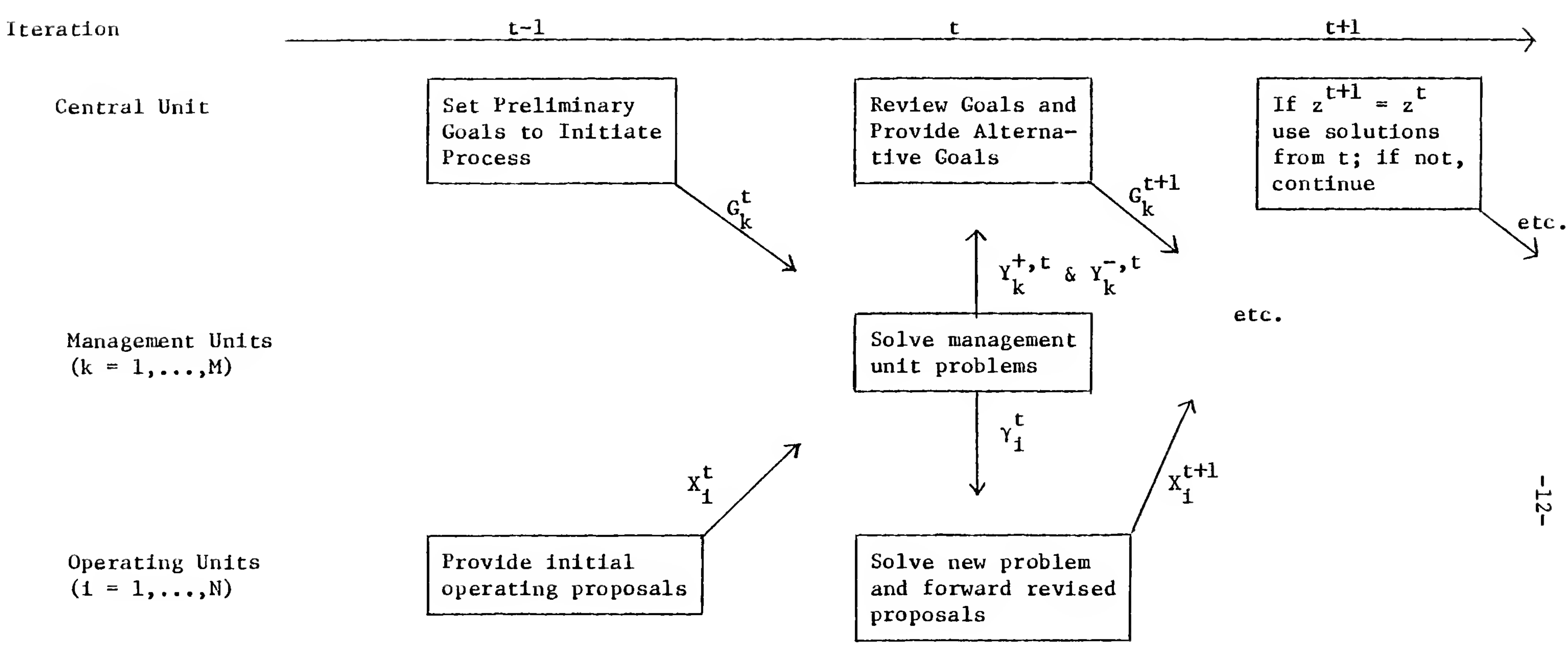

Figure 2

The GHM Solution Procedure

that only operating unit i among its subordinates can generate a new set of proposals, X_i^{t+1}, which can improve the management's external and internal goals, G_k^t and g_k^t, respectively. Given these assumptions, the kth management unit can subtract the contribution of its remaining operating units to determine γ_i^{t+1}. This yields equation (14).

$$\gamma_i^{t+1} = \begin{bmatrix} G_k^t \\ \hline g_k^t \end{bmatrix} - \sum_{\substack{j=r_{k-1}+1 \\ j \neq i}}^{r_k} \sum_{\tau=1}^{t} \begin{bmatrix} B_j \\ \hline B_j' \end{bmatrix} X_j^{\tau} \lambda_j^{\tau} \qquad (14)$$

The assumption used to derive (14) in conjunction with equation (6.k) provide the final algebraic definition of γ_i^{t+1} used by the GHM. This is given in equation (15).

$$\gamma_i^{t+1} = \sum_{\tau=1}^{t} \begin{bmatrix} B_i \\ \hline B_i' \end{bmatrix} X_i^{\tau} \lambda_i^{\tau} - \begin{bmatrix} Y_k^{+,t} \\ \hline y_k^{+,t} \end{bmatrix} + \begin{bmatrix} Y_k^{-,t} \\ \hline y_k^{-,t} \end{bmatrix} \qquad (15)$$

(for i=1,...,N)

At the intuitive level, equation (15) is much less complicated than it looks, and by focusing on one element of an external goal vector the thrust of the revision process can be seen easily. Assume that the kth management unit has a budget over-run of \$.125 million (i.e., the budget element of the $Y_k^{+,t}$ vector equals \$.125 million). The management unit then looks at the budget for operating unit i (for convenience assume that to be \$1.5 million at iteration t). Based upon equation (15) the budget element in γ_i^{t+1} would equal \$1.375 million. Of course these reductions (increases) in operating goals would be applicable to all units subordinate to manager k. Continuing the budget analogy, the effect of providing new Y_i^{t+1} $(i=r_{k-1}+1,\ldots,r_k)$ by management k it to demand a budget cut, if feasible, from each of its subordinates.

After receiving their new goal vectors, Y_i^{t+1}, $(i=1,\ldots,N)$, the operating units solve their individual problems for X_i^{t+1}. While this is going on the central unit formulates its latest problem based upon the $Y_k^{+,t}$ and $Y_k^{-,t}$ deviation vectors from the G_k^t, goal vectors at iteration t $(k=1,\ldots,M)$. Given, these values, the central unit can determine the goal levels, $G_k^{*,t}$ (for $k=1,\ldots,M$) that would have allowed each management unit to meet its previous goals exactly. Equation (16) defines $G_k^{*,t}$.

$$G_k^{*,t} = G_k^t + Y_k^{+,t} - Y_k^{-,t} \quad (\text{for } k=1,\ldots,M) \tag{16}$$

With the $G_k^{*,t}$ vectors in hand, the central can solve for a new set of revised goals subject to the constraints given in equation (3-4).

Once the new goal vectors and operating decisions are determined, they are transmitted to the appropriate management unit, and the process begins again. These information exchanges continue until an overall optimum is reached. The optimum is defined as follows: at each iteration the central unit compares its objective function value, Z^{t+1}, with its previous value Z^t. When the values are equal an "optimal" solution has been achieved at least in the goal programming sense. Proof of this convergence is given in [7, pp. 32-38].

Properties of the GHM's Coordination Mechanism

As noted earlier the Davis GHM is an outgrowth of several previous algorithms [26, 26, 14, and 10]. However, unlike previous models, the

GHM offers significant advantages. Typically the model will converge to a final solution in four iterations or less. Further <u>no</u> heuristic starting procedures are required. In contrast to previous decentralized organization studies by Davis and Talavage [10] and Christensen and Obel [4] these convergence results are extraordinary. Indeed, if one excludes the first iteration, which is required for model initialization, the number of planning, programming, and/or budgetary reviews required by the GHM is strikingly similar to those actually experienced by most decentralized organizations.

The speed of the GHM's convergence rate stems principally from its use of goal deviations and revised target goals as coordinative mechanisms. In the previous decentralized planning models, the key coordination variable has been the simplex multiplier or shadow price. A brief example can explain how a shadow price coordinating mechanism can create convergence problems.

Assume that an organization is very close to achieving one of its goals. Even if the size of the deviation were 10^{-3} units from a goal value, the shadow price of this constraint would have a non-zero value. It is also possible for this shadow price to have the <u>same</u> value in a situation where the deviation is 10^{3} units from the same target goal. In other words, the shadow prices does <u>not</u> necessarily measure an organization's degree of goal achievement. Instead it captures goal non-achievement, but offers no advice on how far goals must be adjusted. Use of goal deviations as a coordination mechanism solves this problem. On a more pragmatic note, the author is aware of relatively few complex organizations that consciously allocate resources on the basis of simplex multipliers. On the other hand, most if not all organizations consistently utilize measures of goal over-achievement or under-achievement in allocating organizational resources.

Unfortunately a comparison of the solution properties of the GHM vis-a-vis previous algorithms is beyond the scope of this study. However, see [11 and 32] for a review of these models.

IV. Specification of the University Model

The planning model presented in this study focuses upon university resource allocation over a three year horizon. As seen in Figure 3, the university is composed of two major units: the Colleges of Arts and Sciences (AS) and Business Administration (BA). In turn each college is composed of several subordinate departments or institutes.

Georgia State University (GSU) served as the structuring guide for the institution presented in this study, and it should be noted that some of the model's characteristics do not conform to the actual organizational structure at GSU. For example, GSU has five colleges; only two, albeit the largest, of these colleges were included in the study. These simplifications were undertaken to keep the dimensions of the problem within reasonable bounds. Accordingly the results of the research, although strongly representative of Georgia State, do not represent a "pure" implementation.

The principal focus of the study was upon the academic units of the university. The intent was to isolate the effects and interactions of student demand, educational quality, and fiscal responsibility upon the university's staffing for academic instruction, research, and public service. Problems of providing incremental or decremental administrative

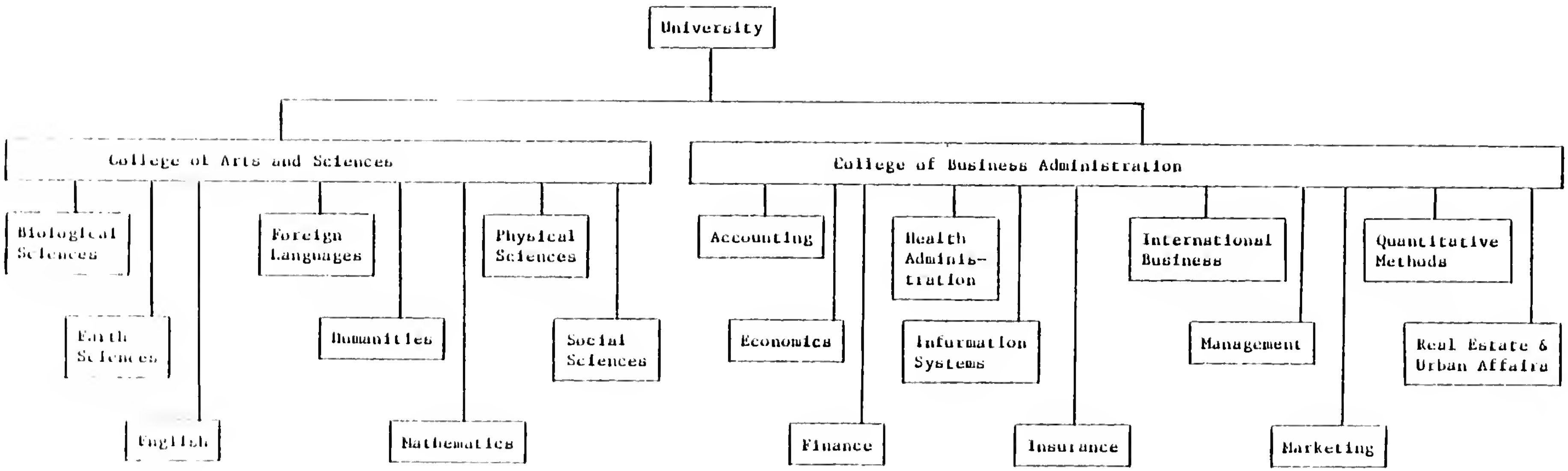

Figure 3

The Organizational Structure of the University Model and support services such as building maintenance, physical security, and major additions to computer, laboratory, library, classroom, and office capacities and resources were not directly included in the model. From an economic perspective many of these requirements are "sunk" or "fixed" commitments. By omitting these services one might infer that their current level is considered optimal; however, such a conclusion is unwarranted. By treating the funding of these "sunk cost" resources as a minimum goal, sensitivity analysis utilizing funding deviations and reallocation alternatives could easily evaluate the potential trade-offs of these fixed commitments.

The model was formulated based upon a nine (and not twelve) month fiscal operation. This was justified on the grounds that summer school teaching and research grant support are typically an appendage to the normal operations of the university. Although the summer lull can provide opportunities for revenue generating executive development seminars and a variety of other public service and educational programs, these summer allocations are exogenous to the model. An overview of the university, college, and department problems as well as a brief summary of the university priority weightings are presented below.

The University Level Problem

A statement of the university level formulation requires the specification of the aggregate university goal vector G_0, the partitioned college goal vectors G_k, k=1,2, and the P_k matrices which relate the college programs and university goals.

For operational purposes the university is assumed to have six performance goals in each planning period. These goals relate to the university's discretionary budget, graduate and undergraduate unfulfilled student demand, minimum levels of university-wide undergraduate core course offerings, and faculty composition.

Panel A of Table 2 provides the values for each of the G_0 elements. The first three elements specify budgets of \$8.0, \$8.5, and \$9.0 million during the next three years respectively. The next six goals are related to unfulfilled undergraduate and graduate student demand. Each of the unfulfilled goal levels is constrained to be less than or equal to zero.

The next three goals focus upon the common freshman-sophomore core curriculum shared by AS and BA students. At GSU, approximately 78% and 44% of the respective freshman and sophomore BA courses are provided by the AS faculty. Thus the quality of both the AS and BA undergraduate programs are heavily dependent upon the allocation decisions made within the AS departments. Because these decisions effect individual college <u>and</u> university programs, it seems entirely reasonable that the university should review these decisions to assure overall program quality.

The final two goal sets involve proportional constraints related to faculty composition and accreditation. These goals are targeted at maintaining excellence in teaching and research and impose the following conditions: (a) at least two-thirds of the university's full time faculty must have completed a Ph.D. or other earned doctorate degree and (b) the percentage of full time equivalent teaching assistants and instructors should not exceed 40% of the entire faculty.

To understand how a zero goal can generate a proportional constraint, assume that MF is the number of faculty without a terminal (e.g., Ph.D.) degree and DF represents the number of terminal degree

Table 2

Components of the University Level Problem

A				B			C	
Elements of the G_0 Vector				University Decision Variables for Period t			The University Level Constraint Set	
	Planning Year				College			
Goal	1	2	3	Goal	AS (k=1)	BA (k=2)		
University Budget Ceiling	$8,000,000	$8,500,000	$9,000,000	Budget	$G_{1,B,t}$	$G_{2,B,t}$	$G_{1,B,1} + G_{2,B,1} \leq 8,000,000$ $G_{1,B,2} + G_{2,B,2} \leq 8,500,000$ $G_{1,B,3} + G_{2,B,3} \leq 9,000,000$	(17.1) (17.2) (17.3)
Unfulfilled Undergraduate Demand	0	0	0	Unfulfilled Undergraduate Demand	$G_{1,UU,t}$	$G_{2,UU,t}$	$G_{1,UU,t} + G_{2,UU,t} \leq 0 \quad V_t$	(17.4)
Unfulfilled Graduate Demand	0	0	0	Unfulfilled Graduate Demand	$G_{1,UG,t}$	$G_{2,UG,t}$	$G_{1,UG,t} + G_{2,UG,t} \leq 0 \quad V_t$	(17.5)
Minimum Univ.-Core Courses	603	615	621	Minimum Univ.-Core Courses	$G_{1,FS,t}$	not applicable	$G_{1,FS,1} \geq 603$ $G_{1,FS,2} \geq 615$ $G_{1,FS,3} \geq 621$	(17.6) (17.7) (17.8)
Terminal Degree Faculty Proportion	0	0	0	Terminal Degree Faculty Proportion	$G_{1,TD,t}$	$G_{2,TD,t}$	$G_{1,TD,t} + G_{2,TD,t} \geq 0 \quad V_t$	(17.9)
Graduate Student Instructor Limits	0	0	0	Graduate Student Instructor Limits	$G_{1,GI,t}$	$G_{2,GI,t}$	$G_{1,GI,t} + G_{2,GI,t} \leq 0 \quad V_t$	(17.10)

faculty. Also assume that the university has a policy that requires that at least two-thirds of its faculty to have a terminal degree. This implies

$$DF \geq 2/3\ [MF + DF]\ . \tag{18}$$

Rearranging (18) and inserting positive and negative deviation variables, d^+_{TD} and d^-_{TD}, yields the following goal programming constraint:

$$-2/3\ MF + 1/3\ DF - d^+_{TD} + d^-_{TD} = 0\ . \tag{19}$$

The role of the university is to generate the right-hand side of this constraint which appears in the colleges' formulation.

In solving its problem, the university partitions the G_0 vector, by solving for the variables defined in panel B of Table 2. Of course these goal assignments are subject to the constraints appearing in panel C of Table 2 (i.e., equations 17.1 through 17.10). For example, the university attempts to allocate college budgets that fall within its overall budget ceilings. It should be emphasized that these "hard constraints" will not necessarily prevent budget overruns, or other undesirable goal violations. This results from the inclusion of the $S_k^{+,t+1}$ and $S_k^{-,t+1}$ (k=1,...,M) deviation vectors in equation (2). However, based upon the priority weighting vectors W_k^+ and W_k^- (k=1,2) supplied by the colleges, the university will attempt to get as close as possible to its desired set of objectives.

The College Problems

Within the GHM framework the colleges review the operating decisions generated by their subordinate departments and recommend revised operating and performance goals based upon external university and internal college policies.

A. Internal Goals

Because the majority of a university course offerings are part of internal college programs, it was not necessary to superimpose external university constraints upon all departmental minimum course offerings. However, there was a need to specify that internal college programs were adequately staffed and funded. To accomplish this, three internal goal sets were imposed; they controlled the colleges' doctoral programs and tenure decisions during the three year planning horizon. These internal goals and constraints are given in equations (20.1) through (20.3) in Table 3. Parenthetically all equations in Table 3 excepting (20.9) appeared in both college's problem formulations; (20.9) was applicable to AS.

An internal goal relating to doctoral seminars was included for several reasons. Viable doctoral programs can provide opportunities and incentives to faculty members to become involved in research and to remain current in areas of specialization. Also Ph.D. students can augment departmental teaching lines, and outstanding doctoral candidates tend to reflect favorably upon the university and can attract top faculty and students. Unfortunately because most doctoral seminars have small enrollments and are taught by the best qualified and most highly paid faculty, doctoral programs may not be at first glance cost effective. Unless minimum goals were placed upon these seminar offerings, they might not be offered.

Table 3

Specification of the AS and BA Internal and External
Goals and Constraints

Internal AS and BA College Constraints and Goals				
# Doctoral Seminars offered in year t for department i	$-d^{+}_{DS,t} + d^{-}_{DS,t}$ =	Target Program Level in year t for department i	$V_{t,i}$	(20.1)
# of internal or external promotions to associate professor in year t	$-d^{+}_{AP,t} + d^{-}_{AP,t}$ =	Target # of Promotions in year t	V_t	(20.2)
# of internal or external promotions to full professor in year t	$-d^{+}_{FP,t} + d^{-}_{FP,t}$ =	Target # of Promotions in year t	V_t	(20.3)
External AS and BA College Constraints and Goals				
Total Departmental Budgets in year t	$-d^{+}_{B,t} + d^{-}_{B,t}$ =	External Budget goal in year t	V_t	(20.4)
Total Unfulfilled Undergraduate Student Demand in year t	$-d^{+}_{UU,t} + d^{-}_{UU,t}$ =	Unfulfilled Undergraduate Demand Goal in year t	V_t	(20.5)

External AS and BA College Constraints and Goals (continued)			
Total Unfulfilled Graduate Student Demand in year t $-d^{+}_{UG,t} + d^{-}_{UG,t}$ =	Unfulfilled Graduate Demand Goal in year t	V_t	(20.6)
$-.667$ [Total Non-terminal Degree Faculty in year t] $+.333$ [Total Terminal Degree Faculty in year t] $-d^{+}_{TD,t} + d^{-}_{TD,t}$ =	Terminal Degree Faculty Goal in year t	V_t	(20.7)
$.6$ [Total FTE Graduate Student/Instructors in year t] $-.4$ [Total Professorial Faculty in year t] $-d^{+}_{GI,t} + d^{-}_{GI,t}$ =	Graduate Student/Instructor Goal in year t	V_t	(20.8)
The total number of AS freshman/sophomore core courses offered in year t $-d^{+}_{ASFS,t} + d^{-}_{ASFS,t}$ =	Minimum Freshman/Sophomore Core Courses Goal in year t	V_t	(20.9)

Equations (20.2) and (20.3) specify the final two internal goals and constraints; they related to the granting of tenure. It was felt including a potential for incorporating future promotions, and/or the hiring outstanding, tenured faculty would greatly enhance. These constraints were not intended to evaluate faculty productivity, but were incorporated as a means of assessing the budgetary faculty composition implications of tenure policies.

B. External Goals

Equations (20.4) through (20.9) specify the remaining goals and constraints for the AS and BA college problems. Of course as mentioned earlier, (20.9) is applicable only to Arts and Sciences. These equations link the right-hand side goal values, generated by the university problem, to the departmental operating proposals. They are targeted at meeting the university stipulated budget, unfulfilled undergraduate and graduate demand, faculty composition, and minimum core course offering goals in each of the three planning periods.

The Departmental Problems

In a decentralized setting, top management is typically interested in the big picture rather than the minute intricacies of operating details. However, as one moves down the organizational hierarchy, it becomes necessary to consider many operating decision interactions in detail. Unfortunately because of space limitations, only a brief overview of the departmental problems can be presented. However, a detailed description is available in [31, pp. 81-107].

A. Departmental Decision Variables

The principal components of the departmental problems are the number, level, and size of course offerings and the type and quality of staffing positions teaching those courses. To link these components each department had seven levels of full time equivalent (FTE) of staff and faculty positions as well as seven levels of course offerings in each of the three planning periods. The staff and faculty variable levels were: (1) secretarial and research associate personnel, (2) graduate student research assistants, (3) graduate student teaching assistants, (4) instructors (nonterminal degree), (5) assistant, (6) associate (tenured), and (7) full (tenured) professors. The course offering levels were: (1) freshman-sophomore core, (2) junior-senior core, (3) junior-senior major-minor, (4) graduate (masters) core, (5) graduate (masters) major, (6) graduate (doctorate) core, and (7) graduate (doctorate) major courses. Also, associated with these course levels are seven variables that capture unfulfilled course demand during each of the three planning periods. Based upon these variables, let $\psi_{k_j,i,t}$, $\chi_{k_j,i,t}$, and $\tau_{k_j,i,t}$ equal staff and faculty positions, course offerings, and unfulfilled student demand associated with department j of college k, at level i in planning period t respectively. Finally let $\beta_{k_j,t}$, the budget of department j of college k during period t equal the sum of department salaries, $\sigma_{k_j,t}$, plus indirect costs $\omega_{k_j,t}$.

B. Departmental Operating Constraints and Goals.

Each departmental formulation incorporated five categories of operating constraints: (a) class size and enrollments, (b) teaching loads and levels, (c) secretarial and research support, (d) direct and indirect budgetary expenses, and (e) tenure obligations. These constraints are given in equations (21.1) through (21.16) in Table 4.

Equations (21.1) through (21.5) attempt to incorporate university policy in regard to average class size and professional teaching levels for the seven course levels offered within the departments. For example (21.1) states that the number of courses offered by department k_j at level i in year t times the average class size for that level, less any unfulfilled student demand in department k_j for course level i in period t will equal the expected student demand for that course level. In addition (21.2) through (21.5) specify that courses offered at various levels cannot exceed the pool of faculty capable of teaching at that level. For example, only professional faculty are allowed to teach doctoral courses; however, as the pool of course offerings expands to include the freshman-sophomore level (21.5) all teaching levels are included.

Equations (21.6) through (21.8) provide minimum and maximum levels of secretarial and departmental administrative support. In a similar fashion (21.9) and (21.10) levy maximum and minimum levels for departmental graduate students research assistant support. Equations (21.11) through (21.14) are related to budgetary items. Respectively they define departmental salaries, minimum and maximum indirect cost levels, and a total departmental budget. Finally (21.15) and (21.16) insure that tenure obligations are fulfilled.

A final set of goal linkage equations is necessary to complete the departmental problem specifications. Because these equations are

Table 4

Departmental Operating Constraints
$(k_j = 1,\ldots,N)$ and $(t = 1,\ldots,3)$

$$\begin{bmatrix}\text{Target Class}\\ \text{Size for}\\ \text{Level } i\end{bmatrix} \lambda_{k_j,i,t} - T_{k_j,i,t} = \begin{bmatrix}\text{Expected Student}\\ \text{Demand for}\\ \text{Department } k_j\\ \text{in period } t\end{bmatrix} \qquad (21.1)$$

$$\sum_{\ell=6}^{7} \lambda_{k_j,\ell,t} \leq \begin{bmatrix}\text{Maximum FTE}\\ \text{Graduate}\\ \text{Teaching}\\ \text{Load Per}\\ \text{Academic}\\ \text{Year}\end{bmatrix} \sum_{i=5}^{7} \psi_{k_j,i,t} \qquad (21.2)$$

$$\sum_{\ell=4}^{7} \lambda_{k_j,\ell,t} \leq \begin{bmatrix}\text{Maximum FTE}\\ \text{Graduate}\\ \text{Teaching}\\ \text{Load Per}\\ \text{Academic}\\ \text{Year}\end{bmatrix} \sum_{i=4}^{7} \psi_{k_j,i,t} \qquad (21.3)$$

$$\sum_{\ell=3}^{7} \psi_{k_j,\ell,t} \leq \begin{bmatrix}\text{Maximum FTE}\\ \text{Undergraduate}\\ \text{Teaching Load}\\ \text{Per Academic}\\ \text{Year}\end{bmatrix} \sum_{i=4}^{7} \psi_{k_j,i,t} \qquad (21.4)$$

$$\sum_{\ell=1}^{7} \psi_{k_j,\ell,t} \leq \begin{bmatrix}\text{Maximum FTE}\\ \text{TA Teaching}\\ \text{Load Per}\\ \text{Academic}\\ \text{Year}\end{bmatrix} \psi_{k_j,3,t} + \begin{bmatrix}\text{Maximum FTE}\\ \text{Undergrad-}\\ \text{uate Teach-}\\ \text{ing Load}\\ \text{Per Academic}\\ \text{Year}\end{bmatrix} \sum_{i=4}^{7} \psi_{k_j,i,t} \qquad (21.5)$$

$$\begin{bmatrix}\text{Minimum FTE}\\ \text{Secretarial/}\\ \text{Faculty Ratio}\end{bmatrix} \psi_{k_j,1,t} \leq \begin{bmatrix}\text{Ratio Equating}\\ \text{\# FTE TA's to}\\ \text{Equal 1 Profes-}\\ \text{sorial Faculty}\\ \text{Secretarial}\\ \text{Requirement}\end{bmatrix} \psi_{k_j,3,t} + \sum_{i=4}^{7} \psi_{k_j,i,t} \qquad (21.6)$$

$$\begin{bmatrix}\text{Maximum FTE}\\ \text{Secretarial/}\\ \text{Faculty Ratio}\end{bmatrix} \psi_{k_j,1,t} \leq \begin{matrix}\text{Ratio Equating}\\ \text{FTE TA's to}\\ \text{Equal 1 Profes-}\\ \text{sorial Faculty}\\ \text{Secretarial}\\ \text{Requirement}\end{matrix} \psi_{k_j,3,t} + \sum_{i=4}^{7} \psi_{k_j,i,t} \qquad (21.7)$$

$$\psi_{k_j,1,t} \geq 2 \qquad (21.8)$$

$$\psi_{k_j,2,t} \geq \begin{bmatrix}\text{Maximum FTE}\\ \text{RA/Faculty}\\ \text{Ratio}\end{bmatrix} \sum_{i=4}^{7} \psi_{k_j,i,t} \qquad (21.9)$$

$$\psi_{k_j,2,t} \leq \begin{bmatrix}\text{Minimum FTE}\\ \text{RA/Faculty}\\ \text{Ratio}\end{bmatrix} \sum_{i=4}^{7} \psi_{k_j,i,t} \qquad (21.10)$$

$$\alpha_{k_j,t} = \sum_{i=1}^{7} \begin{bmatrix}\text{Appropriate Level } i \text{ Salary}\\ \text{of Department } j \text{ of College}\\ k \text{ in period } t\end{bmatrix} \psi_{k_j,i,t} \qquad (21.11)$$

$$\omega_{k_j,t} \geq \sum_{i=4}^{7} \begin{bmatrix}\text{Minimum Indirect}\\ \text{Cost/FTE}\\ \text{Faculty Member}\end{bmatrix} \psi_{k_j,i,t} \qquad (21.12)$$

$$\omega_{k_j,t} \leq \begin{bmatrix}\text{Maximum Indirect Cost/}\\ \text{Total Salary Ratio}\end{bmatrix} \alpha_{k_j,t} \qquad (21.13)$$

$$\beta_{k_j,t} = \alpha_{k_j,t} + \omega_{k_j,t} \qquad (21.14)$$

$$\psi_{k_j,6,t} \geq \begin{bmatrix}\text{\# of Tenured Associate}\\ \text{Professors in period } t\end{bmatrix} \qquad (21.15)$$

$$\psi_{k_j,7,t} \geq \begin{bmatrix}\text{\# of Tenured Full}\\ \text{Professors in period } t\end{bmatrix} \qquad (21.16)$$

departmental "mini" versions of the college internal and external goal a constraints given in equations (20.1) through (20.9) in Table 3, they will not be detailed here. However, one should note that instead of summing across subordinate units, these departmental goal linkage constraints focus upon a single department. As noted earlier not all constraints given in Table 3 are applicable to every department. As an example, a departmental version of (20.1) was applied only to those departments offering doctoral programs. Also only AS departments incorporated a minimum freshman-sophomore core course constraint.

Goal Deviation Priority Weightings

The power and flexibility of goal programming result from its ability to get "as close as possible" to a desired set of policy conditions [3, p. 217]. This is achieved through a multiple objective satisfying criteria function. The intracies of the priority weighting vectors seen in equation (1), (5.k), and (11.i) are rather cumbersome. Because they are given elsewhere [3, pp. 109-112], only a few summary details are presented here.

Several interesting aspects emerged from the college's priority rankings. First there was a lack of symmetry between the weights assigned by AS and BA to budget overruns, with AS assigning a much higher priority to suppressing positive deviations. Although it was possible to scale their weightings to achieve parity, this was not done in order to explore the implications of disparate priorities on the university's allocation of resources.

Two additional divergencies were noticable in the priority weightings. BA placed higher priorities on its doctoral programs and tenure/

promotion goals. On the other hand, AS was more concerned with its undergraduate programs. These weightings were not surprising given the current educational environment characterized by an oversupply of potential faculty and undersupply of students in AS disciplines.

V. The Model's Solution

The computer memory requirements necessary to solve a centralized version of GSU model are enormous. The overall problem would have over 7,200 variables and 2,800 constraints. Using a standard linear programming (L.P.) code its solution would require inversion of a matrix containing slightly more than 19.4 million elements. These dimensions exceed the absolute machine limits of most computer's memory or core by a considerable factor.

One of the major benefits of decomposition algorithms such as the GHM is that these huge problems can be decomposed into reasonably sized subproblems. For the GSU model the smallest of subproblems was the central unit; it contained 69 variables and 36 constraints. The largest problems were in the BA departments. These departments contained 375 variables and 141 constraints. Unfortunately, the man-hours required to formulate and solve, seriatum, the various iterative stages of the algorithm through conventional linear programming solution codes was prohibitive. Assuming that five iterations are required for convergence, the GSU model would require 528 (22 subproblems x 5 hours x 5 solutions) man-hours. Further, this manual data manipulation dramatically increased the probability of errors creeping into the subproblems' formulations and results.

Thus it was necessary to write a computer program that could implement the Davis algorithm and remain a maximum core limit of 100,000 computer words. (A computer word can store a number's value with reasonable accuracy.) Although a FORTRAN code [8, pp. 187-235] that implemented a previous version of the Davis algorithm was modified to implement the GHM, the L.P. optimization subroutines within the original program worked poorly. Thus it was necessary to install a new set of optimization subroutines [21] in the GHM's code.

The GHM FORTRAN code and L.P. subroutines were written and tested on a Control Data Corporation CYBER-175 computer. The GHM code offered two significant benefits: computational ease and speed. For example data input preparation for the GSU problem required eighty man-hours. Central processing unit (CPU) compilation and execution time was excellent. For twelve iterations 297.5 CPU seconds were required: for four iterations 97.7 seconds were required.

Solution Characteristics of the Initial Formulation

The initial GSU problem formulation converged to a final solution in twelve iterations. These results were rather disappointing in view of the fact that previous testing of the algorithm on two test problems required no more than five iterations.

Although the model generated no unfulfilled graduate or undergraduate student demand in any planning year, this was achieved at a considerable price. Most dramatic were budget deficits of approximately $1.0, $1.1, and $1.2 million in years one through three respectively. With few exceptions the departments relied upon teaching assistants and temporary instructors rather than assistant professors. In view of severe budget restrictions such policies might be acceptable stopgap measures; however, the long-term implications of these hiring policies are likely to be disastrous and could result in the stagnation of teaching innovations and research.

The model was not totally successful at meeting the colleges' internal goals. Although minimum support was generated for doctoral programs, the results of the promotion goals were inconsistent in that no promotions were incorporated in the BA solution. This result can be attributed to the algorithm's "perception" that BA was generating the university's deficits.

As noted earlier, the AS penalties associated with budget overruns was significantly higher than BA (100 versus 75). This higher level of priority weighting could be interpreted as "political clout." In fact analysis of the colleges' budget deviaitions revealed that all deficits occurred in BA. From a behavioral viewpoint, a scenario in which a bureaucratic organization with realtively more political power receives a disproportionately large share of available funding is plausible. But from the university administration's viewpoint, this type of situation cannot be tolerated. In light of these and other characteristics it was necessary to revise the original formulation and to ameliorate the solution's shortcomings through sensitivity analysis.

Problem Revision and Sensitivity Analysis

In trying to eliminate budget deficits several alternative strategies were available. These included increasing average class sizes and faculty teaching loads, decreasing faculty raises and indirect expenses, and allowing "less expensive" graduate student teaching assistants and instructors to teach upper level courses. Clearly each of these alternatives created trade-offs in maintaining faculty morale, educational quality, and institutional effectiveness. Further, accreditation standards imposed by the American Assembly of Collegiate Schools of Business (AACSB) and the University System's Board of Regents regulations severely limited several courses of actions. Although numerous policy alternatives were tested with varying degrees of success, the compromise version of the model reported here focused upon five principal areas.

The first policy change involved an increase in average class size. Even though these increases could potentially lower education quality, the Carnegie Commission has endorsed this approach [2]. The second change attempted to counterbalance the potential dimunition of educational quality precipitated by class size increases. In the original formulation, temporary instructors were allowed to teach at all levels except doctoral level seminars. (See equations (21.2) through (21.5).) In the revised version temporary instructors were allowed to teach only freshman-sophomore and junior-senior core courses. It was anticipated that these changes would force the model to incorporate additional assistant professors into the final solution, thereby injecting fresh viewpoints into departments and improving research and teaching innovation.

Based upon the size of the university's deficit, it was unlikely that campus-wide increases in class size could totally offset funding shortfalls. As a result the third change in university policy focused upon limiting the size of departmental indirect costs. Although unpleasant, the indirect expense reductions were clearly preferable to salary reductions.

The fourth revision in GSU formulation attempted to provide parity in the budget priorities of the AS and BA colleges. In the revised model both colleges' budget overrun penalty weights were increased and equated so that no college had an advantage in bureaucratic bargaining power.

The final changes made in the original model eliminated the internal promotion goals for both colleges and modified the constraints specifying the minimum number of departmental doctoral seminars to equal the number of seminars observed in the original solutions. This level of doctoral program support was felt to be more than adequate. Initially the promotion goals were intended to reward excellence in research, teaching, and public service. Unfortunately sensitivity analysis revealed that their ability to achieve this objective was at best poor, and they were dropped from the model. It should be noted that potential future promotions can be incorporated into the formulation within the department constraints. (see equations (21.15) and (21.16).) As a result omitting promotion constraints does not severely limit the formulations applicability.

Results of the Revised Formulation

The modified version of the model reached a final solution after four iterations, and unlike the previous versions, all university and internal college goals were achieved. Several aspects of the solution are noteworthy. One of the most pleasant and surprising aspects was rapid convergence. Although changes in priority weights was expected to improve convergence, the improvements exceeded expectations. Not only did the changes in budget priorities improve computational time and expense, they generated small budget surpluses for BA in years one and two and AS for year three. As one might expect these restrictive budgets had a direct effect on departmental research support and indirect cost allocations, but none of these support levels was felt to be below minimum acceptable levels.

Perhaps the most disappointing aspect of the revised formulation was the model's inability to incorporate significant levels of assistant professors in its solutions. In fact careful analysis of teaching loads and class offerings revealed that a few departments had surplus tenured professors. The stark reality of such a scenario emphatically drives home the need to continually evaluate admissions, tenure, academic, and budgetary policies over reasonable planning horizons.

Based upon the complexity and interactions of departmental, college, and university policies, the timely analysis of the major issues facing all levels of a university's administration can be extremely difficult. However, the computational ease engendered by the use of the GHM provides a convenient and straightforward solution procedure that allows testing and sensitivity analysis of an unlimited number of alternative strategies and policies. As in all mathematical allocation models, the quality of the algorithm's results are "only as good as the accuracy with which the model describes the reality of [a particular] institution" [28, p. 45]. Although the proposed GHM cannot guarantee an "optimal" allocation of an organization's resources, it can, if properly employed, significantly improve upon the rationality and reasonableness of resource allocation decisions in many decentralized, hierarchical organizations.

VI. Summary and Conclusions

The purpose of this study was to develop a rational approach based upon the Davis generalized hierarchical goal decomposition model (GHM) that could be useful in allocating resources within a decentralized university. Based upon the algebraic structure of this decomposition technique, a university resource allocation model was developed for Georgia State University (GSU). The model was formulated to encompass a three year planning horizon, and dealt with three levels of the university, structuring subproblems for the university administration, two colleges, and nineteen departments. Certain simplifying changes were incorporated to keep the problem's size within reasonable bounds; however, the resulting model's fomulation strongly resembled Georgia State.

The size of the GSU formulation was enormous. Without the use of the Davis algorithm, a matrix defining the overall problem would contain slightly less than 20 million elements. A FORTRAN computer program was written to implement the GHM on a Control Data Corporation CYBER-175 computer. Computational requirements of the model were excellent.

The results of the original formulation were disappointing. Accordingly revisions and sensitivity analysis was conducted to improve the model's solution characteristics. These changes generated dramatic improvements in several areas, and on balance the model appears to offer a reasonable approach to the dilemma currently faced by many university administrators. Even in an environment characterized by multiple and conflicting institutional goals, a lack of unanimity in regard to organizational priorities, and severe financial restrictions, the model has performed well. This is not to infer that additional refinements and changes in the GSU formulation and/or GHM are unwarranted. For example, in developing the GSU formulation, questions concerning incremental or decremental administrative and support services and facilities were omitted. In view of the model's relatively short planning horizon can be justified. However, future research should expand the model's planning horizon in order to focus upon the impact that all operating decisions can have on long-run institutional viability.

Although the computer algorithms presented in this study have been based upon a linear objective function-goal programming solution procedure, alternative functional forms could be superior. For example, if a non-linear instead of linear functional form objective function were used, the magnitude of the cumulative penalties associated with deviation values could increase at an increasing rate as undesirable deviations become larger. In addition to consideration of a nonlinear objective function, research investigating the possibility of utilizing an integer or mixed integer programming code in conjunction with a nonlinear optimization procedure should be undertaken. Clearly the need for continuing research remains.

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